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Plant nutrients recovery from aflatoxin B1 contaminated corn through co-composting

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ABSTRACT

Climate change and incorrect agronomic practices in crop management, before and after harvesting, can cause an increase in the annual quantity of aflatoxin B1 (AFB1) contaminated corn production. The aim of this study was to evaluate the suitability of AFB1 contaminated corn for composting, in order to recover plant nutrients and degrade AFB1.

Two different mixtures were prepared (mixture PS comprising 12% contaminated corn + 40% pig slurry + 40% wood chips + 8% cereal straw w/w and mixture OFMSW comprising 14% contaminated corn + 43% municipal organic solid waste + 43% wood chips w/w) and treated through static composting using passive aeration. During composting, several parameters were analysed to assess the possible influence of AFB1 on the process. The quality of the final compost was also evaluated and the AFB1 residues were determined through HPLC.

The evolution of the composting was not affected by AFB1 and the mycotoxin concentration was strongly reduced at the end of the process (the AFB1 removal was 85.7% and 97.3% in mixture PS and OFMSW, respectively). The final composted material was characterised by high agronomic quality and, thus, composting may represent a suitable strategy to recover plant nutrients from aflatoxin B1 contaminated corn.

1. Introduction

Aflatoxin B1 (AFB1) is a secondary metabolite produced by certain species of *Aspergillus* fungi (e.g. *A. flavus* and *A. parasiticus*). This mycotoxin is included in Class I of the International Agency for Research on Cancer (IARC) classification due to its carcinogenic, hepatotoxic and mutagenic effects [1]. AFB1 contamination may occur during the cultivation, harvest, post-harvest and storage of several crops (peanuts, cotton and corn in particular). Although more than 100 countries have determined tolerance limits for AFB1 in food, it is estimated that about 5 billion people worldwide suffered from exposure to this mycotoxin [2]. European legislation defines the maximum level of AFB1 in different raw materials for human food (EC Regulation 1881/2006[43] as amended in EC Regulation N° 165/2010, Table 1)[44] and in feedstock for animal feed (0.02 mg kg^{-1}, EC Directive 02/32/EC)[42]. Within this regulatory framework, disposal and recycling procedures for contaminated corn are still not defined. Both animal feed and human food contaminated by AFB1 are widely considered waste materials to be disposed of through landfill or incineration.

Of all the different methods studied for aflatoxin decontamination, microbial degradation was extensively investigated. The main aerobic microorganisms that were found to be effective for AFB1 degradation are fungi (*Absidia repens*, *Alternaria* spp., *Candida utilis*), bacteria (*Bacillus* spp., *Pseudomonas* spp., *Lactobacillus* spp.), protozoa (*Tetrahymena pyriformis* W) and yeasts (*Saccharomyces cerevisiae*) [3–7]. Most of the microorganisms that are able to degrade AFB1 are also present in composting mixtures [8,9]. Thus, composting may represent a suitable strategy to reduce AFB1 contamination in corn and to recover plant nutrients and organic matter from this waste. Composting is the natural process of organic matter decomposition, operated by microorganisms under monitored aerobic conditions [10]. Aerobic treatment enhances the suitability of organic wastes for soil applications by converting them into organic fertilisers [11,12,13,14]. In addition, a decrease in organic pollutant content has also been reported during composting [15,16]. The application of compost to agricultural soils plays an important role in sustaining soil fertility, as it is a source of humified organic matter and plant nutrients and, thus, contributes to sustainable agricultural production [17].

Few studies have been conducted concerning the effectiveness of composting for the removal of AFB1. Akoto et al. [18] demonstrated

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Table 1
Maximum levels for aflatoxin B1 contamination in feedstuffs. Modified from EC regulation N° 1881/2006 (Annex, Section 2), last amended in EC Regulation N° 165/2010.

Foodstuff	Maximum AFB1 level ($\mu g\,kg^{-1}$)
Groundnuts to be subjected to sorting or other physical treatment, before human consumption	8.0
Nuts, maize and dried fruit to be subjected to sorting, or other physical treatment, before human consumption	5.0
Groundnuts, nuts and dried fruit processed products	2.0
All cereals and products derived from cereals	2.0
Following species of spices: *Capsicum* spp., *Piper* spp., *Myristica fragrans*, *Zingiber officinal*, *Curcuma longa*.	5.0
Processed cereal-based foods and baby foods for infants and young children	0.1
Dietary foods for special medical purposes intended specifically for infants	0.1

that AFB1 did not affect the aerobic process at laboratory scale by using peanut meal as a model matrix. Nevertheless, the possible recovery of AFB1 contaminated corn through composting has never been investigated. Thus, the aim of the present research was to evaluate: (1) the correct evolution of composting in the presence of AFB1 contamination, (2) the quality of the final compost and (3) the AFB1 removal at the end of the process. To achieve this purpose, AFB1 contaminated corn was co-composted with two different organic materials (pig slurry and the organic fraction of municipal solid wastes).

2. Material and methods

2.1. Organic materials and corn contamination

The composting trials were performed using the following organic materials: (1) chopped corn (particle size < 2 mm, certified for AFB1 absence), (2) pig slurry (PS) and (3) the organic fraction of municipal solid waste (OFMSW). The two co-composting matrices (PS and OFMSW) were selected to assess if the contaminated corn recovery could be achieved with different co-composting matrices.

For the composting experiment, chopped corn, pig slurry, bulking and absorbing agents (wood chips and cereal straw, particle size < 50 mm) were collected from local farmers, whereas OFMSW was collected from a local company which manages urban wastes.

Once in the laboratory, the samples were divided into two aliquots: the first one was stored at 4 °C until the start of the experiments and the second one was frozen at -18 °C for the analytical determinations.

Aflatoxin B1 (AFB1 isolated from *A. flavus*, Sigma Aldrich, St. Louis, MO, USA) standard solution (10 $mg\,kg^{-1}$ in methanol) was used to contaminate the chopped corn in order to obtain a final AFB1 concentration of 100 $\mu g\,kg^{-1}$ dry weight [19].

2.2. Composting experiment

Co-composting, bulking and absorbing agents were added to AFB1 contaminated corn to modify the physical properties (bulk density, air-filled porosity and moisture) to avoid water loss from the mixture and provide adequate air circulation. Based on these considerations, two mixtures were prepared according to the following proportions (fresh weight basis):

- Mixture PS: 12% contaminated corn + 40% pig slurry + 40% wood chips + 8% cereal straw;
- Mixture OFMSW: 14% contaminated corn + 43% organic fraction of municipal solid waste + 43% wood chips.

The main physico-chemical characteristics of both mixtures were determined and reported in Table 2. In particular, air-filled porosity was calculated from the wet bulk density, as described by Alburquerque et al. [20]. The C/N ratio of both mixtures was not adjusted since composting can be carried out effectively at low C/N ratios to reduce the requirement for a bulking agent [21].

Mixtures were prepared and treated in experimental composters (0.6 m x 0.6 m x 0.8 m = 0.288 m^3) at outdoor conditions. Both treatments were carried out through static composting and passive aeration was maintained only through the porosity of the mixtures treated. Environmental and composting temperatures were monitored daily during the active phase by using a temperature probe (Stainless Steel Temperature Probe, Vernier, Beaverton, USA). The thermophilic phase was considered to have been concluded when the mixture temperature was stable, between 30 and 40 °C.

Afterwards, the mixtures were placed in two open containers for the curing phase (60 days). Samples were collected at 0, 30 and 90 days. Once in the laboratory, collected samples were divided into three portions: the first one was stored at 4 °C, the second one was frozen at -18 °C and the third one was oven-dried at 50 °C; they were then crushed in a mortar, sieved to 0.5 mm and thoroughly mixed for analytical determinations.

2.3. Analytical methods

Total solids (TS), volatile solids (VS), total organic carbon (TOC), total Kjeldahl-N (TKN) and ammonium–N (NH_4^+-N) were analysed according to standard methods [22]. Organic N was then calculated by taking the difference between TKN and NH_4^+-N. The pH and the electrical conductivity (EC) were measured in a solid/water suspension (1:10 w/v) by using a glass electrode (pH-Meter Basic 20+, Crison Instruments, Barcelona, Spain) and a conductivity probe (Ec-Meter Basic 30+, Crison Instruments, Barcelona, Spain), respectively. Total P was measured spectrophotometrically after digestion of the samples with concentrated HNO_3/H_2O_2 [12]. For the heavy metals determination, samples were digested with HNO_3 and H_2O_2 using a microwave oven (Milestone Inc. ETHOS One, maximum power 800 W) [22]. Flame atomic emission spectrophotometry was used for total K determination in the same extracts. Heavy metals concentrations were determined by flame atomic absorption spectrophotometry using a Shimadzu AA-6800 apparatus (Shimadzu Corp., Tokyo, Japan). Humic-like substances were extracted and purified, as described by Ciavatta et al. [23] and C concentration in the extracts was determined through high-temperature combustion (680 °C, Pt catalysed) followed by CO_2 infrared detection (Analyser multi N/C 2100S, Analytic Jena, Überlingen, Germany). The degree of humification (DH) was calculated as a percentage of the (HA + FA)/TEC ratio, where (HA + FA) is the amount of humic and fulvic acids and TEC is the total extractable C in alkali solution. Water Extractable Organic C (WEOC) was extracted from dry samples with deionized water for 24 h at room temperature [24]. The suspensions were centrifuged at 4,200 rpm and filtered on 0.45-μm membrane filter and WEOC concentration was determined by an automatic C analyser (Analyser multi N/C 2100S, Analytic Jena, Überlingen, Germany). The distribution of WEOC between two operationally defined fractions, the so-called hydrophilic (Hi) and hydrophobic (Ho) fractions, was carried out using the method described by Massaccesi et al. [25]. The C concentration in the two fractions was then determined through an automatic C analyser (Analyser multi N/C 2100S, Analytic Jena, Überlingen, Germany). A modified phytotoxicity test, employing seed germination, was used to determine the germination index (GI) [26].

Table 2
Characterisation of organic materials and mixtures used in composting treatments.

	Units	Corn	Pig slurry	OFMSW	Wood chips	Cereal straw	Mixture PS	Mixture OFMSW
Moisture	%	14.0 ± 0.2	85.0 ± 0.3	69.7 ± 1.0	13.7 ± 0.6	10.6 ± 0.2	55.3 ± 3.1	66.9 ± 1.8
C/N		25.0	14.0	17.1	49.7	91.4	21.8	17.2
Bulk Density	kg L^{-1}	0.64 ± 0.0	0.89 ± 0.1	0.80 ± 0.0	0.23 ± 0.0	0.02 ± 0.0	0.53	0.53
Total Kjeldahl N	%	1.5 ± 0.1	3.1 ± 0.4	1.3 ± 0.0	0.8 ± 0.2	0.5 ± 0.0	1.2 ± 0.0	1.7 ± 0.3
Total Organic C	%	37.5 ± 1.2	43.4 ± 2.0	22.2 ± 0.9	39.8 ± 1.0	45.7 ± 0.8	26.1 ± 3.6	29.3 ± 4.0
Air-filled porosity	%	n.d.	n.d.	n.d.	n.d.	n.d.	53.7	53.7

Mean ± SD, n = 3.
n.d.: not determined.
Data expressed on dry weight basis.

The AFB1 extraction, clean-up and determination was carried out according to the method described by Akoto et al. [18]. Briefly, AFB1 was extracted from dry compost samples with methanol/water (60/40% v/v) and NaCl (5%). After filtration, the samples were purified through an immuno-affinity column (NeoColumn for Aflatoxin WB, Neogen, Lansing, USA) and then analysed on a PE 200 HPLC apparatus (Perkin Elmer, Milano, Italy). Peaks were detected by fluorescence with an excitation wavelength of 360 nm and emission wavelength of 440 nm. The results were confirmed by using the standard addition method.

The aflatoxin B1 removal at the end of the process was calculated using the following equation Eq. (1):

$$\text{AFB1 removal (\%)} = \frac{\text{AFB1 T0 (}\mu\text{g kg}-1) - \text{AFB1 T90(}\ \mu\text{g kg}-1)}{\text{AFB1 T0(}\ \mu\text{g kg}-1)} \times 100 \quad (1)$$

3. Results and discussion

3.1. Composting process evaluation

Fig. 1 reports the temperature values measured during the active phase of the composting, compared to the environmental temperature. The temperature profile over time is a key factor to check the correct development of composting. Increasing temperatures in the first days in both of the mixtures tested indicate the ideal composition of the initial mixtures and an efficient composting process [12]. During composting, temperature peaks should be attained and they should be maintained for a long time in order to obtain a complete sanitation of the biomass [27]. Temperature grew quickly after the start of the experiment, reaching the maximum values before the fifth day (75.5 °C and 74.8 °C for mixture PS and OFMSW, respectively). In both mixtures, temperature persisted higher than 55 °C for almost one week, allowing a proper sanitation of the waste material from animal and plant pathogens, as well as for weed seed inactivation [28]. With regard to the active phase, it can be suggested that the presence of AFB1 does not affect microbial activity, since an optimal temperature development was observed in both treatments.

Table 3 shows the N dynamics in the two mixtures during composting. The TKN increase was caused by the organic matter loss and the bacterial nitrogen fixation [29,30]. Moreover, TKN contents did not differ from the values observed in other typologies of compost (e.g. compost derived from agricultural wastes, municipal solid wastes and sewage sludge) [13,31,14]. From an agronomic point of view, the final TKN values obtained (2.2% and 2.1% dry weight for the PS and OFMSW compost, respectively) can be considered positively. In the PS mixture, NH_4^+-N decreased significantly during the active phase and then remained constant along the curing phase (Table 3). In fact, PS mixture was characterised by a higher NH_4^+-N content with respect to the OFMSW one and, consequently, the quick temperature increase caused the rapid volatilisation of NH_4^+-N during the active phase [32]. Conversely, in the OFMSW mixture, the NH_4^+-N slightly increased during the thermophilic phase due to protein hydrolysis and, afterward, it decreased in the maturation phase. Nevertheless, final NH_4^+-N concentrations in the two composts were not different and they were far from the values considered to be responsible for phytotoxicity [33]. The largest part of the TKN was represented by organic N in both of the final composts, as expected at the end of a composting process [29]. In fact, organic N increased mainly due to the microbial NH_4^+-N immobilisation.

Table 3 also shows the Total Organic Carbon (TOC) and C/N ratio evolution during composting. TOC significantly decreased during composting and TOC losses were 43.6% and 46.4% in the OFMSW and PS mixture, respectively. This TOC decrease is attributable to the mineralisation of the organic matter that produces CO_2 and heat [26]. At the end of the process, the PS and OFMSW compost showed a decreased

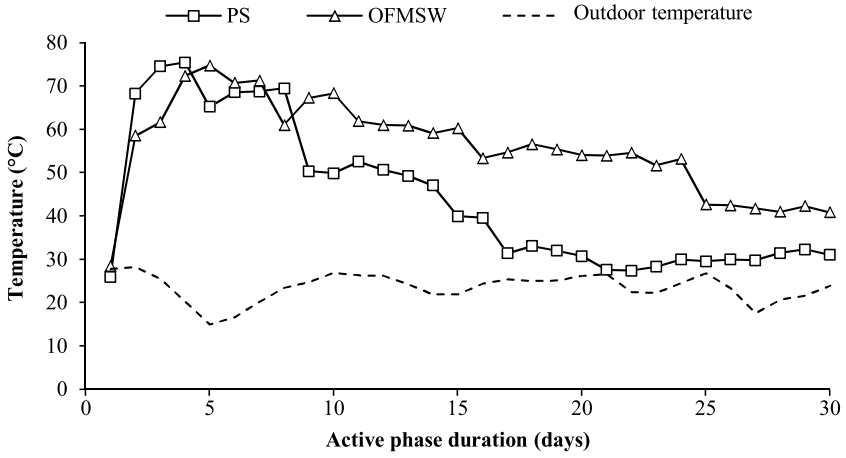

Fig. 1. Temperature profile during active composting phase of mixture PS, mixture OFMSW and outdoor temperature.

Table 3
Evolution of total Kjeldahl N (TKN), NH_4^+-N, organic N, total organic C (TOC), organic matter (OM) loss and C/N ratio during composting in PS and OMSFW mixtures.

	Units	PS			OFMSW		
		0 d	30 d	90 d	0 d	30 d	90 d
TKN	%	1.2 ± 0.1	1.9 ± 0.3	2.2 ± 0.1	1.7 ± 0.3	1.6 ± 0.1	2.1 ± 0.0
NH_4^+-N	%	0.15 ± 0.01	0.06 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.10 ± 0.01	0.03 ± 0.01
Organic N	%	1.05	1.84	2.15	1.63	1.50	2.07
TOC	%	34.0 ± 4.7	26.2 ± 3.2	18.2 ± 1.5	38.1 ± 5.3	21.5 ± 0.7	21.7 ± 0.1
C/N		28.3	13.8	8.3	22.4	13.4	10.3
OM loss	%	–	49.0	62.1	–	79.7	80.2

Mean ± SD, n = 3.
Data expressed on dry weight basis.

Table 4
Evolution of water extractable organic C (WEOC) and its hydrophilic (Hi) and hydrophobic (Ho) fractions, Hi/Ho ratio and WEOC/Organic N ratio during composting in PS (pig slurry) and OMSFW (organic fraction of the municipal solid waste) mixtures.

	Units	PS			OFMSW		
		0 d	30 d	90 d	0 d	30 d	90 d
WEOC	%	2.0 ± 0.2	1.9 ± 0.1	1.5 ± 0.0	5.7 ± 0.1	2.1 ± 0.1	1.2 ± 0.0
Hi	%	0.7 ± 0.0	0.6 ± 0.1	0.5 ± 0.0	2.4 ± 0.1	0.7 ± 0.0	0.4 ± 0.1
Ho	%	1.2	1.3	1.0	3.3	1.4	0.8
Hi/Ho		0.6	0.5	0.5	0.7	0.5	0.5
WEOC/Organic N		1.7	1.0	0.7	3.5	1.4	0.6

Mean ± SD, n = 3.
Data expressed on dry weight basis.

C/N ratio, which was in the optimum range for mature compost [11,34]. Both composting processes showed typical OM losses, confirming the optimisation of both treatments and the lack of AFB1 inhibition on the microbial activity [11,12].

Concerning the WEOC evolution during composting (Table 4), this parameter decreased in both treatments and the decrease was more evident in the OFMSW trials (79%) with respect to the PS one (25%). The difference of WEOC did not correlated to different process efficiency but was probably due to the higher initial WEOC content in the OFMSW mixture, compared with the PS one. The results of the fractionation of WEOC into its hydrophobic and hydrophilic fractions and the Hi/Ho ratio showed that, during the active phase of composting, the hydrophilic fraction is particularly responsible for the decrease of the WEOC. This evidence suggests that the major process involved in the loss of WEOC during the active phase could be the oxidation of the labile organic C that is part of the Hi fraction [26]. The Hi/Ho ratio decrease throughout the process could be related to the contribution of the hydrophobic constituents, derived from the degradation of lignocellulosic materials, to a faster mineralisation of the Hi fraction with respect to the Ho fraction and to the transformation of hydrophilic components into hydrophobic ones, by abiotic polymerisation and condensation reactions that occur in solution [26]. The PS and OFMSW compost presented optimal Hi/Ho ratios, which were in accordance with values commonly used to assess compost stability [35].

Final WEOC/organic N values were compatible with the values defined by Bernal et al. [11] to assess compost stability (< 0.7).

3.2. Quality of the final compost

Table 5 shows the results of the physico-chemical characterisation of the initial mixtures (0 d) and final compost (90 d) compared to limit values established by the Italian legislation concerning fertilisers [36].

Moisture content was strongly reduced with respect to the initial mixtures in both composts, mainly due to the heating of the mass during the active phase that caused water evaporation. The low moisture content may represent an advantage for the management of these materials, in terms of reduced transport volumes and costs. During composting, pH increased markedly in the OFMSW trial, mainly due to the removal of organic acids and to the release of ammonia following protein hydrolysis [12]. The two composts showed similar pH levels (7.3 and 7.2 for the OFMSW and PS compost, respectively) which are typical of mature compost, as described by Bernal et al. [11]. Both composts showed low soluble salt contents (estimated by the electrical conductivity), avoiding the salinisation or other negative effects which can occur after applying compost to soil [37].

The high organic N to TKN ratio found in the PS and OFMSW compost represented a positive property for these materials [16]. In fact, organic N is characterised by a slow mobilisation that may provide the best long term benefit for soil and crops. The low NH_4^+-N and soluble salts content of both composts may be responsible for their high germination index (112.9% and 103.6% for OFMSW and PS compost, respectively). In fact, it is well known that these compounds, as well as volatile fatty acids and phenols, are often responsible for phytotoxicity [16,26,33].

The compost produced in the PS and OFMSW trials were characterised by high amounts of P and K, which were comparable to those showed by other compost and biosolid typologies [13,31]. Total P was higher in the PS compost (0.9%) with respect to the OFMSW compost (0.4%) due to the high amount of P that characterises pig slurries [38].

DH and humic-like substances content are agronomic criterion for compost quality, indeed the agricultural value of a compost increases when the organic matter reaches a high level of humification [11]. In this study, the DH was 66.1% and 66.2% in PS and OFMSW, respectively, whereas the humic and fulvic acids content was higher than 7%, demonstrating good compost maturation. The increased DH and humic-like substances content in the compost, with respect to the initial mixtures, was the result of a complex dynamic equilibrium. Specifically, the degradation of non-humified compounds and the release of compounds which are then incorporated into the humification pathways, occurred simultaneously during composting, gradually leading to more humified, polymerised and oxidised compounds [11].

The heavy metal content of the compost was less than the

Table 5
Chemical characterisation of the initial mixtures (0 d) and mature compost produced (90 d) from the OFMSW and PS treatments compared to limit values established by Italian legislation concerning fertilisers [36].

	Unit	OFMSW		PS		[36]
		0 d	90 d	0 d	90 d	
Moisture	%	66.9 ± 1.8	36.9 ± 0.1	55.3 ± 3.1	31.5 ± 3.9	< 50
pH	pH unit	3.3 ± 0.0	7.3 ± 0.0	7.3 ± 0.3	7.2 ± 0.0	6.0–8.8
Electrical conductivity	dS m^{-1}	3.3 ± 0.8	2.3 ± 0.3	1.3 ± 0.2	2.1 ± 0.2	–
Total Kjeldahl N	%	1.7 ± 0.3	2.1 ± 0.1	1.2 ± 0.0	2.2 ± 0.1	–
NH_4^+-N	%	0.1 ± 0.0	< 0.1[a]	0.2 ± 0.0	0.1 ± 0.0	
Organic N	%	1.6	2.10	1.0	2.10	–
Organic N/ Total Kjeldahl N	%	94.1	98.4	83.3	97.8	> 80
Total Organic C	%	29.3 ± 4.0	16.7 ± 0.1	26.1 ± 3.6	14.4 ± 1.1	> 20
C/N		17.2	8.0	21.8	6.5	< 25
Total P	%	0.2 ± 0.0	0.4 ± 0.1	0.4 ± 0.0	0.9 ± 0.2	–
Total K	%	1.4 ± 0.2	1.3 ± 0.2	1.0 ± 0.2	1.4 ± 0.2	–
Degree of humification	%	37.5 ± 11.1	66.1 ± 5.4	51.3 ± 6.0	66.2 ± 6.7	–
(Humic + Fulvic) acids	%	6.1 ± 2.6	8.4 ± 0.2	7.0 ± 1.0	9.3 ± 2.0	> 7
Germination index	%	n.d.	112.9 ± 1.1	n.d.	103.6 ± 1.0	> 60
Zn	mg kg^{-1}	n.d.	140.2 ± 13.2	n.d.	223.2 ± 8.2	< 500
Cu	mg kg^{-1}	n.d.	45.8 ± 4.9	n.d.	33.2 ± 0.7	< 230
Pb	mg kg^{-1}	n.d.	91.9 ± 13.5	n.d.	84.5 ± 20.0	< 140
Cd	mg kg^{-1}	n.d.	0.3 ± 0.1	n.d.	0.2 ± 0.0	< 1.5
Ni	mg kg^{-1}	n.d.	22.4 ± 0.4	n.d.	21.7 ± 2.1	< 100
Hg	mg kg^{-1}	n.d.	< 0.5[a]	n.d.	< 0.5[a]	< 1.5
Cr VI	mg kg^{-1}	n.d.	< 0.1[a]	n.d.	< 0.1[a]	< 0.5

Mean ± SD, n = 3.
n.d.: not determined.
Data expressed on dry weight basis.
[a] Detection limit of the method used.

established limit values, avoiding the risk of soil contamination after compost application. Among the heavy metals analysed, Zn showed the most considerable difference between the PS and the OFMSW compost, which was attributable to the use of pig slurry [38,39].

The compost produced in the two trials corresponded to the requirements established by the Italian legislation [36]. Thus, it can be stated that AFB1 does not affect the evolution of the composting process and the quality of the final materials. Moreover, it was demonstrated that co-composting of contaminated corn can take place with both an agricultural by-product (PS)or an organic waste (OFMSW). The simultaneous recycling of different wastes (AFB1 contaminated corn and OFMSW) appears to be an interesting strategy to recover organic matter and plant nutrients from these types of waste.

3.3. Aflatoxin B1 analysis

Results of the AFB1 analysis showed that the mycotoxin content was significantly reduced during composting in both experiments (Table 6). The AFB1 contents at the beginning of the experiment was already reduced with respect to the initial corn contamination (100 μg kg^{-1} dry weight) due to the dilution effect produced by the mixing of the chopped corn with the co-composing matrices. At the end of composting, the AFB1 content decreased from 13.04 to 0.35 μg kg^{-1} dry weight in the OFMSW treatment, whereas in the PS treatment the AFB1 content was reduced from 12.20 to 1.75 μg kg^{-1} dry weight. The average AFB1 removal during the two trials was 91.5%, which was a really high value if compared to the AFB1 removal efficiency known for other decontamination methods (chemical, physical and biological) [4,40]. Akoto et al. [18] found an average AFB1 removal of 58.5% during a laboratory composting experiment, using peanut meal as the model matrix. In the present experiment, the concurrence of several AFB1 decontamination agents during composting (microorganisms, high temperature, NH_4^+- N, light irradiation) may definitely be responsible for the stronger removal of this mycotoxin at the end of the aerobic treatment with respect to the one found by Akoto et al. [18].

Table 6
Aflatoxin B1 concentration in the initial mixtures (0 days), in the final compost (90 days) and AFB1 removal.

	Unit	OFMSW	PS
AFB1 (T = 0)	μg kg^{-1}	13.04 ± 0.21	12.20 ± 0.08
AFB1 (T = 90)	μg kg^{-1}	0.35 ± 0.01	1.75 ± 0.21
AFB1 removal	%	97.30 ± 0.11	85.70 ± 1.74

Mean ± SD, n = 3.
Data expressed on dry weight basis.

The microorganisms present in the composting mixtures may be responsible for the AFB1 degradation during the aerobic treatment. In fact, Vanhoutte et al. [40] described these microorganisms (e.g. fungi species such as *Armillariella tabescens* and bacteria species such as *Pseudomonas putida*) as being effective for AFB1 decontamination. They proposed that AFB1 degradation may follow two different pathways: (1) modification of the difuran ring and (2) modification of the coumarin structure. These mechanisms are known to produce low toxic AFB1 metabolites (e.g. dihydrodiol-derivates and aflatoxin D). Although the AFB1 removal was high in both trials, the OFMSW treatments showed a significantly higher AFB1 removal with respect to the PS one. Since the two trials showed similar temperature and NH_4^+-N values, it may be stated that the different removal was attributable to differences in the microbial population.

Soil microorganisms could complete the AFB1 removal after compost application, as already described in the literature [5,7].

Other than composting, anaerobic digestion was also studied as an AFB1 decontamination method, i.e. Salati et al. [41] found an AFB1 removal of 78% and 42% in batch and semi-continuous trials, respectively. The integration of anaerobic and aerobic treatments (e.g. through digestate composting) may represent a suitable strategy to remove AFB1 and simultaneously recover energy and nutrients from contaminated corn.

4. Conclusions

AFB1 did not affect the co-composting of AFB1 contaminated corn with other matrices (pig slurry and the organic fraction of municipal solid wastes). The quality of both of the final composts met the requirements of the Italian legislation concerning fertilisers. Composting resulted in a strong removal of AFB1, probably due to the occurrence of different decontamination agents. Thus, the aerobic treatment may represent a suitable strategy to recover organic matter and plant nutrients from contaminated materials. In addition, co-composting of AFB1 contaminated corn with the organic fraction of municipal solid waste may also allow the simultaneous valorisation of two waste materials and the AFB1 removal.

Nevertheless, the analysis of the microbial community and the changes in their profiles during the composting of AFB1 contaminated corn should be properly assessed.

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